MER EDL Wind Mitigation Efforts

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3/26/02

Entry, Descent & Landing (EDL) Scenario

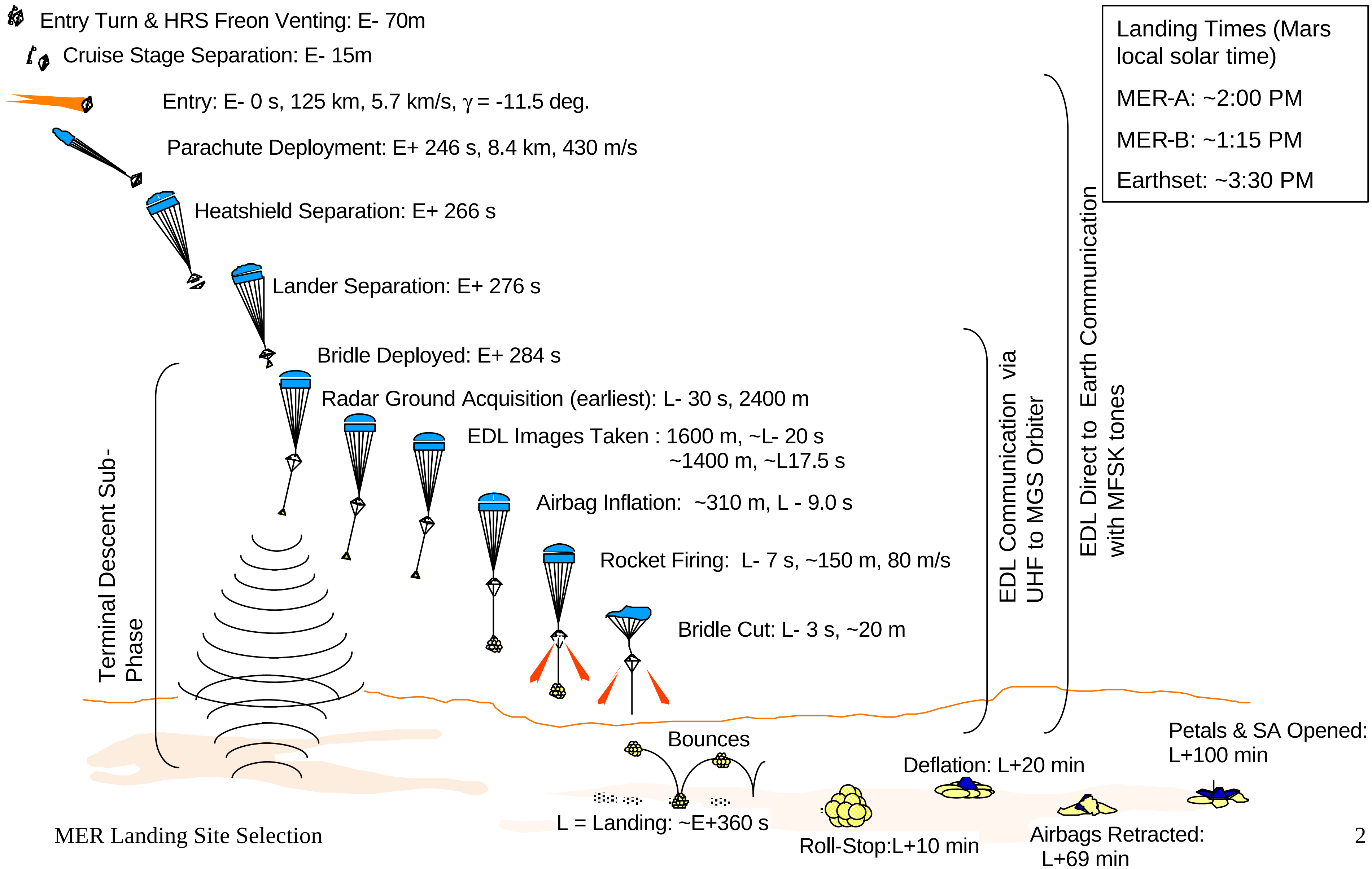
Mars Exploration Rover

Landing Times (Mars local solar time)

MER-A: ~2:00 PM

MER-B: ~1:15 PM

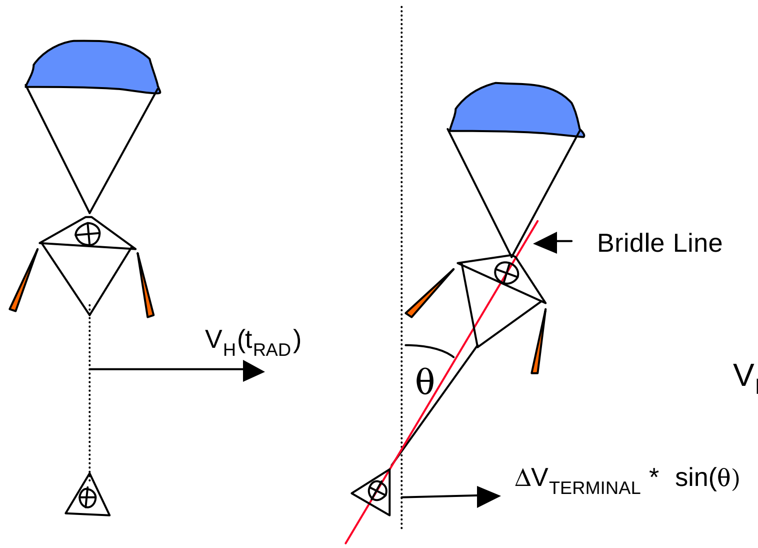
Earthset: ~3:30 PM



The Horizontal Velocity Problem

Mars Exploration Rover

- **Two Major Sources of Horizontal Velocity**
  - **Wind-driven oscillations that result in non-zero angles between the vertical and the bridle line will induce a horizontal velocity approximately equal to V_T*sin(q) due to off-vertical RAD firing.**
    - **Caused by wind shears (high frequency components) that excite a resonant dynamics mode, but are too short in duration to cause the parachute system to follow.**
    - **In the frequency domain, these correspond to wavelengths on the order of several hundred meters.**
  - **Horizontal velocity of lander at the instant of RAD ignition will be transmitted directly to the horizontal impact velocity.**
    - **Caused by sustained winds (low frequency components) that act on the lander for greater than ~20 seconds and cause the parachute system to follow.**
    - **In the frequency domain, these correspond to wavelengths greater than 1 km.**
  - **The horizontal velocity at the time of first impact is equal to the (vector) sum of the two major components.**



$$V_H(t_{impact}) = V_H(t_{RAD}) + \Delta V_{TERMINAL} * \sin(\theta)$$

Recent MER Airbag Drop Test Experience

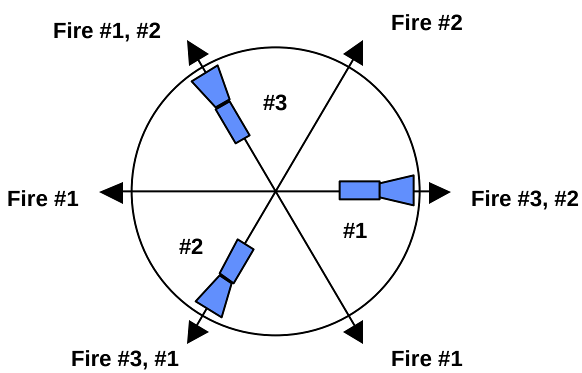
- **October 2001**
  - **First opportunity to test pristine set of airbags under MER conditions.**
  - **Original goal to converge the MER design and enable flight qualification to begin in Jan-02 was not achieved.**
    - **Never-before seen end-cap and gore-panel seam failure.**
    - **Easy, puncture-like slice through of all abrasion layers and bladder, attributed to excessive internal pressure.**
  - **Subsequently, test goals were changed to demonstrate minimum acceptable performance, and to gather data regarding sensitivity to other performance and environmental parameters.**
- **Jan-Feb 2002**
  - **Modifications to airbag to eliminate Oct failure modes**
    - **Re-enforced abrasion and bladder layers**
  - **Tests were successful**
- **Baseline Flight Configuration selected last week.**
- **Conclusions:**
  - **Maximum tangential velocity = 16- 20 m/s, maximum normal velocity = 12+ m/s.**
  - **On 0.3 - 0.5 m rocks**
  - **Airbags alone can not solve the horizontal velocity problem**

Shear Wind Mitigation

- **Added the Transverse Impulse Rocket Subsystem (TIRS) in late '00 to mitigate shear wind effects (considered at the time to be the worse of the wind effects).**
  - With a backshell IMU, measure and perform backshell attitude control to counter wind shear-induced attitude effects during the main rocket burn.
  - HOWEVER without a ground-relative velocity measurement TIRS can not correct for lateral motion from steady winds since a sensor was absent in the system design.

TIRS Control Description

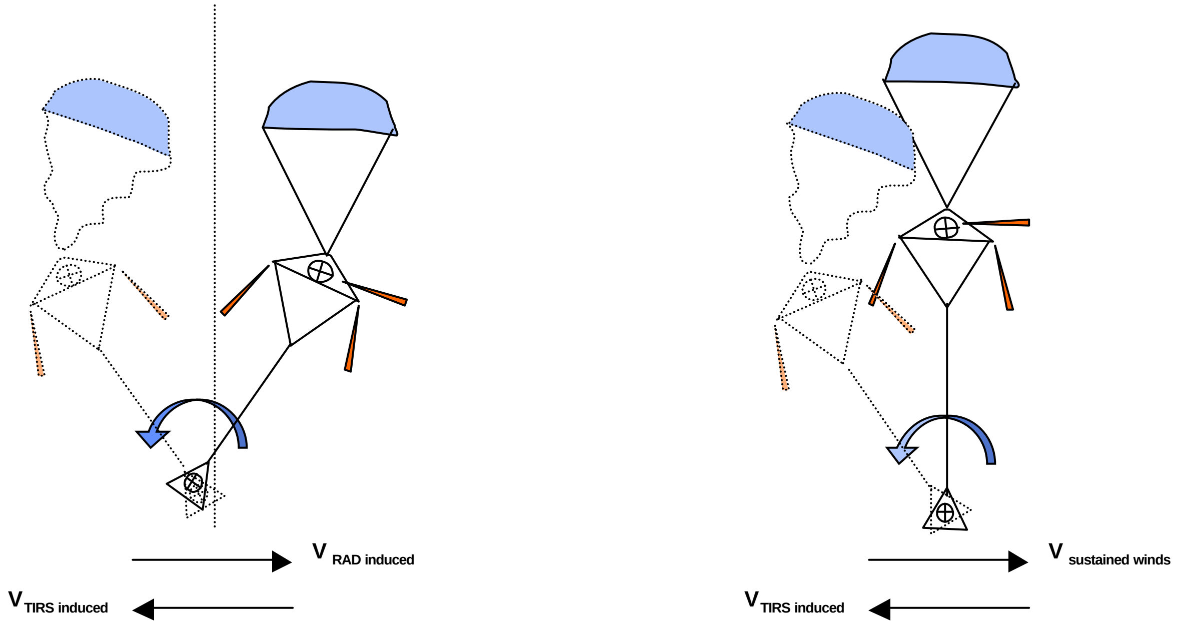
- **The three TIRS rockets are spaced at 120° increments around the backshell.**
  - **At the time of RAD ignition, the control logic will fire zero, one or two TIRS motors to apply a thrust to the backshell in one of six directions spaced 60° apart.**
- **Rockets are sized to provide 750 N*s of impulse, thereby providing 15 m/s of induced horizontal velocity capability.**
  - **Rocket size chosen to maximize system success probability across a wide variety of wind profiles.**
  - **With this propellant load, TIRS could be accidentally activated on a windless day without causing the horizontal impact velocity to exceed capability (16 m/s).**
- **Statistical performance analysis of the TIRS system will need to account for the associated errors introduced by direction and magnitude unitization**



TIRS Control Description

Mars Exploration Rover

- **Three small rockets that point through the backshell center of mass will fire at the time of RAD ignition to change the average bridle-line angle of the system during the RAD burn.**
  - **To mitigate a wind shear situation, TIRS rocket combinations will be selected to such that the average bridle angle during the RAD burn is as close to vertical (zero) as possible, thereby eliminating the induced horizontal velocity.**

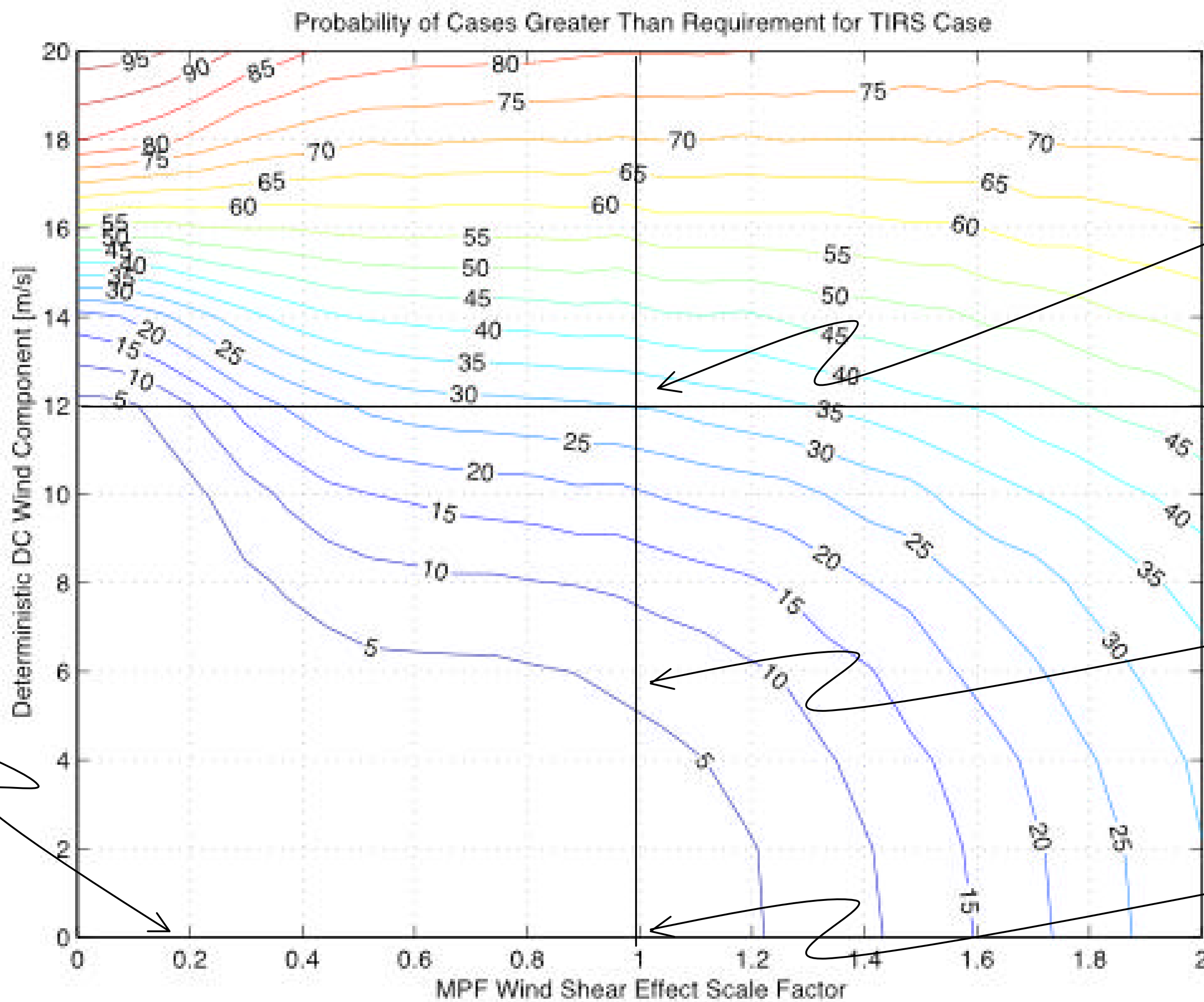


Steady State Wind Mitigation

- **Concern about steady winds affecting touchdown velocity grew as**
  – increased (modeled) knowledge of steady state winds grew AND
  – it was evident that the airbag capability could not be pushed further.
- **Proposed Descent Imager Motion Estimation System (DIMES) in late 01 as a relatively simple and low impact method to directly measure ground-relative horizontal velocity.**
  – Viking and MPL used Doppler Radar system for similar purposes - new Radar would be prohibitively difficult to integrate into MER.
  – Using existing wide angle camera and electrical and software interfaces as well as existing image rectification and correlation algorithms.
  – Design & fab is on schedule. Integration, and V&V ahead.
- **Jan 25, 2003, Wind Risk meeting discussed the rationale for a horizontal wind sensor.**
  – Project then committed to initiate the DIMES implementation.
  – Flight System ECR and associated liens were approved to accommodate the new camera.

MER "w/ TIRS" Probability of Failure with various winds w/ 16 m/s (tangential) Airbag

Mars Exploration Rover



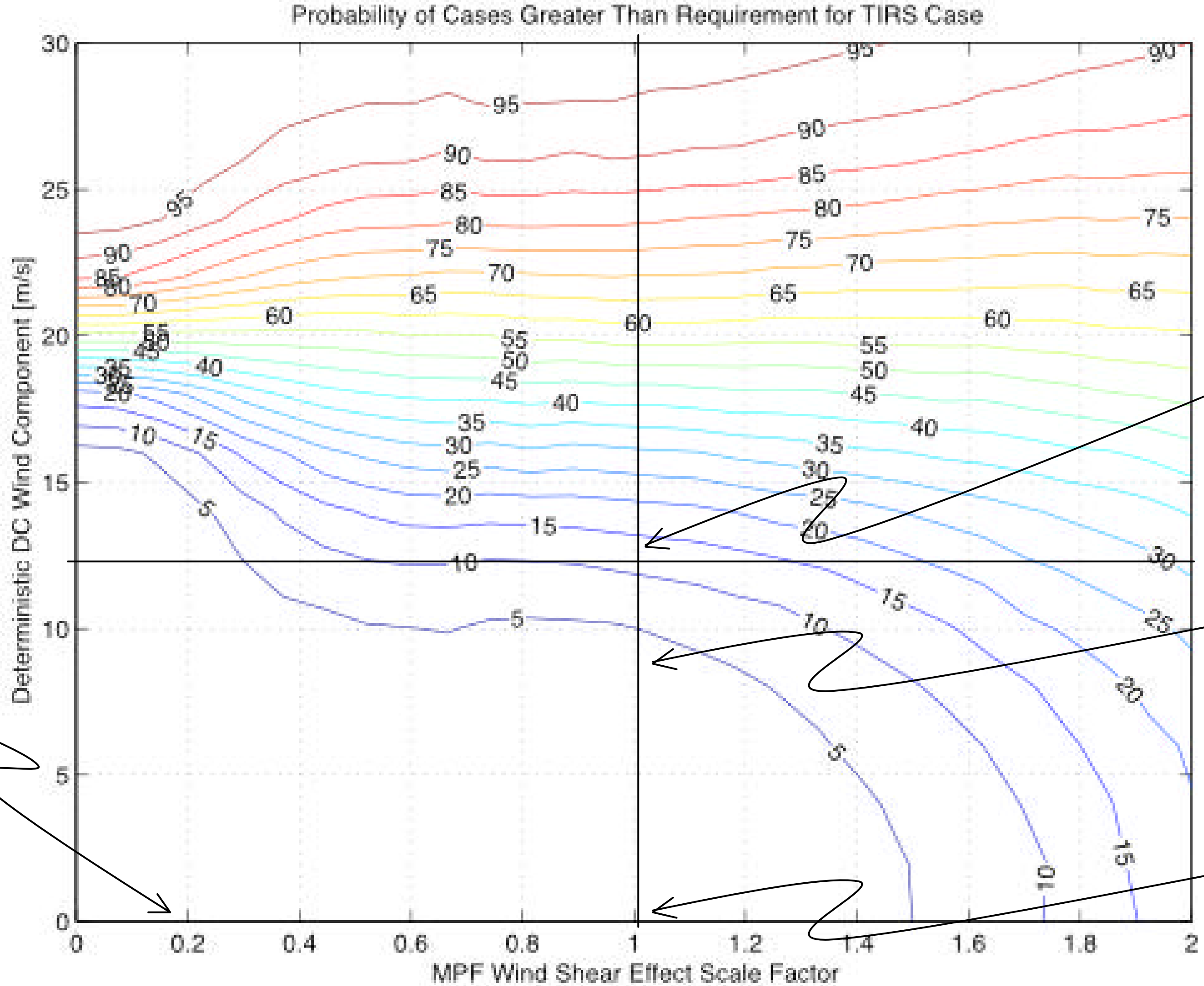
MER prob of TD Failure assuming MPF wind shear and 12 m/s steady state wind = 30%

Pathfinder: Wind Shear above KSC, Florida (conservative?)

MER Prob of TD failure <5% !

Pathfinder: Zero mean, 7 m/s 3-sigma

MER “w/ TIRS” Probability of Failure with various winds w/ 20 m/s (tangential) Airbag



Pathfinder: Zero mean, 7 m/s 3-sigma

MER prob of TD Failure assuming MPF wind shear and 12 m/s steady state wind = 11%

Pathfinder: Wind Shear above KSC, Florida (conservative?)

MER Prob of TD failure <<5% !

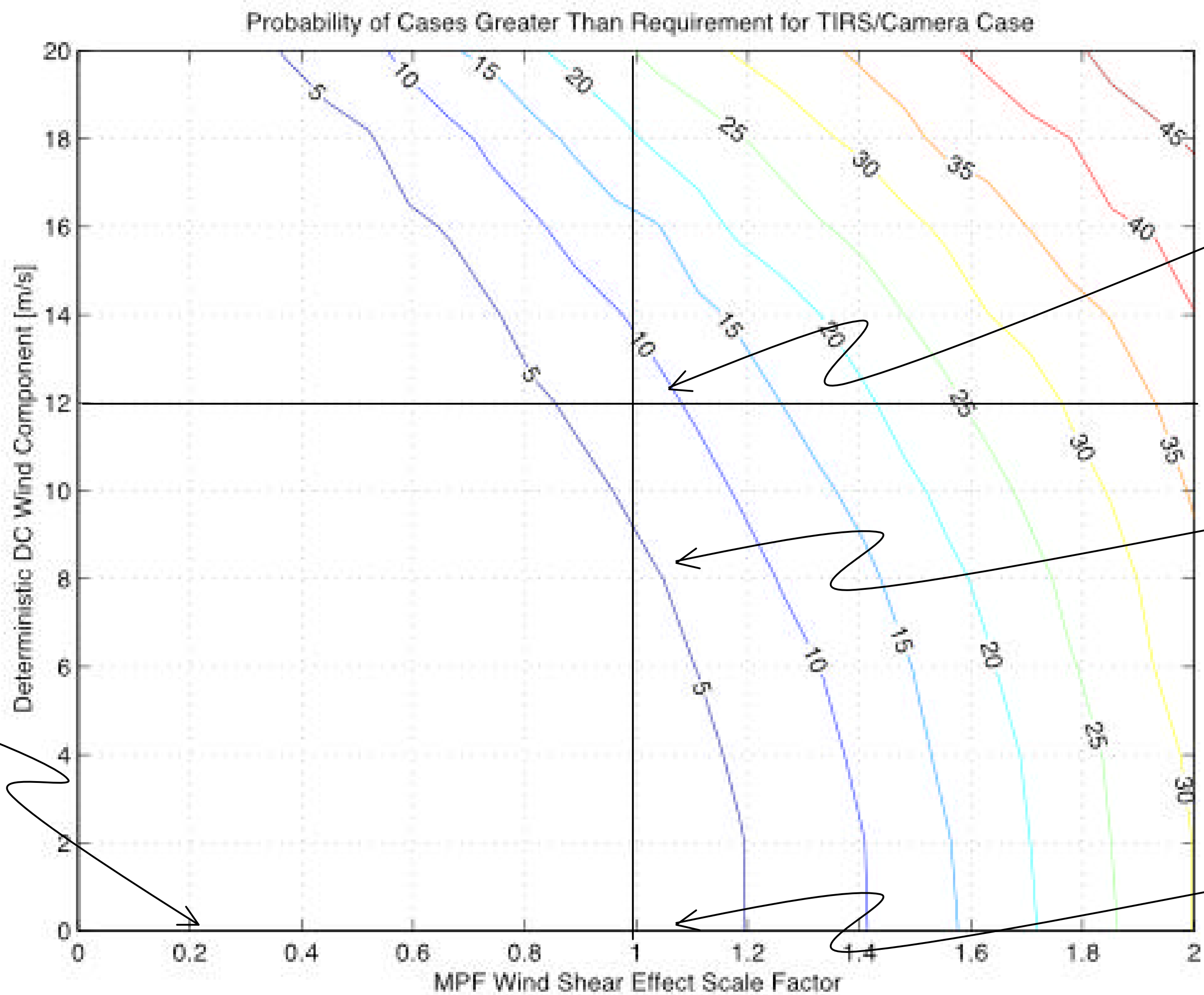
Note: This is for 1st bounce only.

Proposed Solution to Steady State Wind Problem

- **Add a sensor to measure true surface-relative horizontal velocity (as high as 30 m/s) accurate to about 5-7 m/s (3 sigma).**
  - **Sloppy measurement accuracy is acceptable because the control is so sloppy.**
- **Incorporate the estimated (IMU-propagated) velocity into the estimated RAD-induced velocity estimate (vector addition) prior to hand-over to the TIRS firing logic**
  - **Selects the 1 out of six directions to fire TIRS rockets at RAD ignition.**
- **Assuming the sensor can make a reliable estimate, this system results in significant robustness in the face of uncertain steady state winds.**
  - **Ability to handle steady state winds falls off slowly above 14 m/s.**
    - **See following slide.**

MER “TIRS+ Reliable Sensor” Probability of Failure with various winds w/ (tangential) Airbag

Mars Exploration Rover



MER prob of TD Failure assuming MPF wind shear and 12 m/s steady state wind = 7%

Pathfinder: Wind Shear above KSC, Florida (conservative?)

Pathfinder: Zero mean, 7 m/s 3-sigma

MER Prob of TD failure <<5% !

* Assumes MER Capability of 16 m/s horizontal velocity

DIMES proposal
(Descent Image Motion Estimation Subsystem)

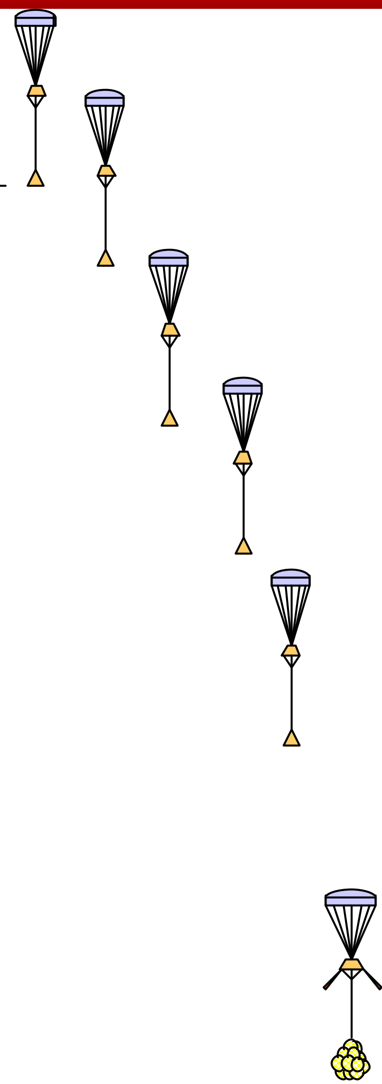
Mars Exploration Rover

- **Need a horizontal velocity sensor**
  - **Use of doppler radar or other sensors have proven prohibitive to implement on MER (volume, electronics interfaces, etc.)**
- **Use a spare descoped Sun Camera electronics optics and interface, mount it to the base of the lander and use image rectification and correlation software to produce a ground-relative velocity estimate.**
- **Design must be demonstrated to ensure that it "does no harm" in that it does not make the landing reliability worse AND it must improve the robustness of the system against wind effects at the time of RAD ignition.**
- **So far, work has shown that this will indeed work in even some of the lowest contrast / albedo sites studied to date.**

DIMES Scenario

80 m/s terminal velocity

30 m/s Horizontal Velocity



altitude	time	
2400 m	RI-27.5s	Initial Radar Acquisition
1600 m	RI-17.5s	first image acquired Initialize DIMES IMU propagation
		Read out first image (2.5s)
1400 m	RI-15s	second image acquired Start processing 1st Image
		Read out second image (2.5s)
1200 m	RI-12.5s	third image acquired Start 2nd image processing and correlation process
		Read out third image (2.5s)
1000 m	RI-10s	Continue 1st correlation processing Begin 3rd image verification process when finished with correlation
280 m	RI-1s	Provide answer to TIRS algorithm
200 m	RI-0s	RAD firing
0 m		

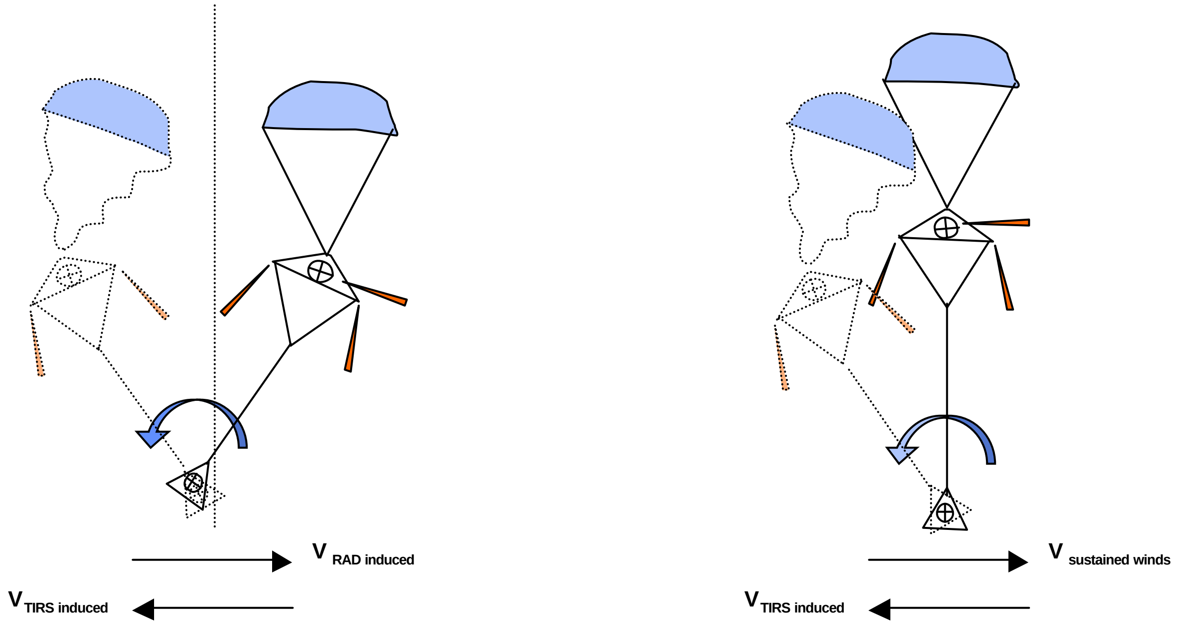
200 m

Note: NOT to scale

TIRS & DIMES Control Description

Mars Exploration Rover

- **Three small rockets that point through the backshell center of mass will fire at the time of RAD ignition to change the average bridle-line angle of the system during the RAD burn.**
  - **To mitigate a wind shear situation, TIRS rocket combinations will be selected to such that the average bridle angle during the RAD burn is as close to vertical (zero) as possible, thereby eliminating the induced horizontal velocity.**
  - **To mitigate a sustained wind situation, TIRS rocket combinations will be selected to such that the average bridle angle during the RAD burn results in intentionally inducing a horizontal velocity (via V_T*sin(q)) equal and opposite to the wind.**



Current Terminal Descent System Description

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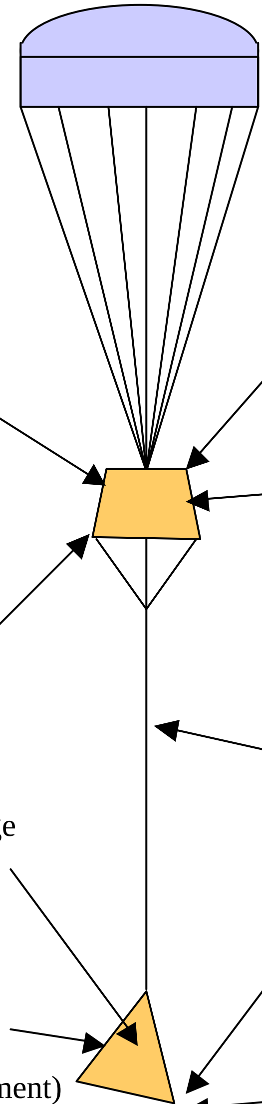

Parachute: Disc-gap-band parachute used to slow the System from supersonic speeds to a terminal descent velocity between 60 to 80 m/sec

Backshell: Structure that contains the lander during entry. Also supports the RAD Motors, and TIRS Rockets and BIMU

Backshell IMU (BIMU):
Gyro and accelerometer package
Litton: LN-200SN
(Mounted inside backshell)

Transverse Impulse Rockets:
Three rockets pointed through the CG of backshell
Used to change orientation of backshell during RAD Motor firing
Single rocket thrust:
Single rocket Impulse:

Retro-Rockets (RAD Motors):
Three (3) Retro-rockets used to slow the descent of the system just prior to landing
Single rocket thrust:
Single rocket Impulse:

Bridle: Structurally and electrically connects the Lander to the Backshell during terminal descent.

Rover IMU (RIMU):
Gyro and accelerometer package
Litton: LN-200SN
(Located inside rover)

Decent Imager: 45 degree FOV frame transfer imager
Used to acquire images used to determine horizontal velocity

Lander: Structure that contains the rover and all of the landing support equipment (airbag system, EDL batteries, righting equipment)

Radar Altimeter (RAS): Measures Altitude,
used to determine vertical velocity
Honeywell <insert part number>
Max altitude 2400 m (8000 ft)

Conclusions

- **Current work demonstrates that DIMES will statistically improve the probability of safe landing in the presence of steady statewinds and wind shears.**
- **Much work remains, but the effort and scope fit well within our pre-launch EDL development schedule.**